Electromagnetic and Electronic Systems

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1. Nanotube-Enhanced Ultracapacitors for Improved Electrical Energy Storage

Sponsors
MIT Energy Initiative (MITEE)
Ford-MIT Alliance

Project Staff
R. Signorelli, E. Flores, S. Warnock, A. Williams, J. Kassakian, J. Schindall

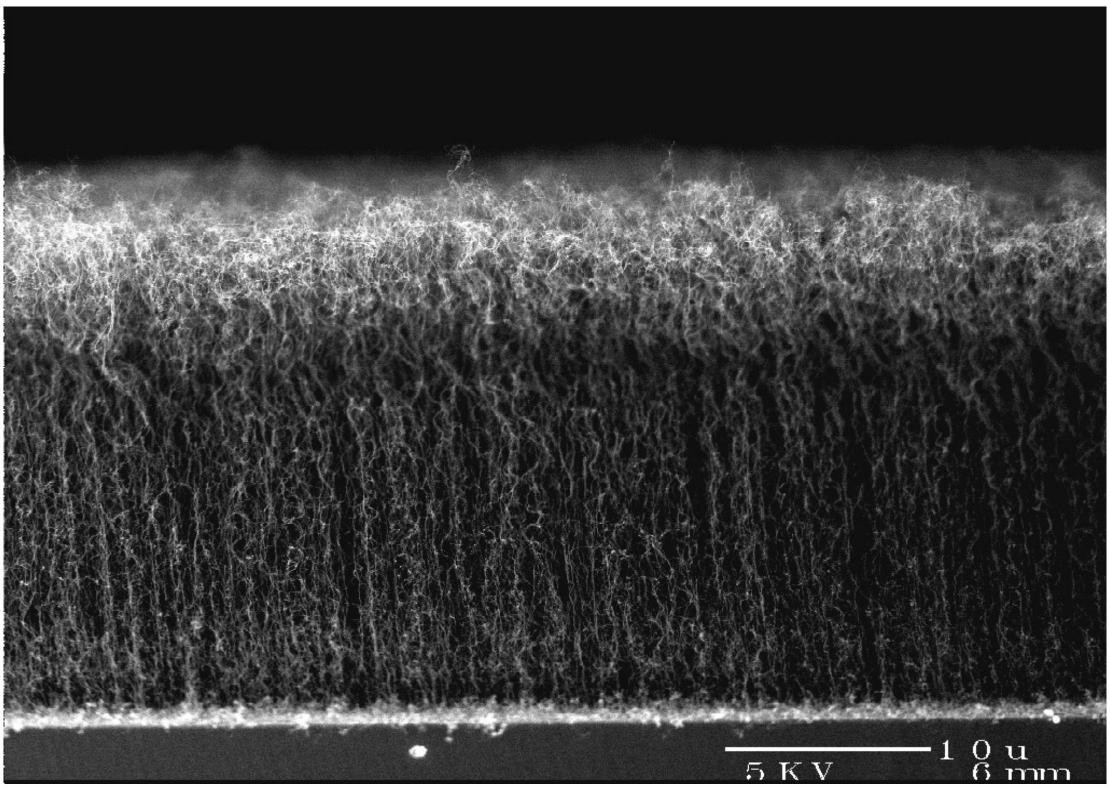
The purpose of this project is to develop a practical electrical energy storage device that combines the long life and rapid charge-discharge capability of a capacitor with the much higher energy storage capacity of a rechargeable battery. The work is based on an intriguing device called an Electronic Double-Layer Capacitor (EDLC), commonly known as an ultracapacitor, which was developed by Standard Oil in the 1960's. Existing ultracapacitors utilize aluminum electrodes coated with a layer of activated carbon, separated by a porous insulator and impregnated with an electrolyte. When a voltage is applied, positive electrolyte ions coat the negative electrode and negative ions coat the positive electrode, forming capacitors with incredibly high surface area (the surface of the activated carbon) and very small charge separation (1/2 the diameter of the electrolyte ions). Today's ultracapacitors have almost unlimited lifetime (millions of cycles, since there is no redox chemical reaction), can be charged or discharged in just a few seconds (typically 100X the power density of an equivalent-sized chemical battery), operate well at low temperatures (no redox reaction), and use benign materials (primarily aluminum, carbon, and cellulose). However, the limitation is that the energy density of an ultracapacitor is typically about 5% of the energy density of an equivalent-sized lithium ion battery.

Our research is intended to increase the energy storage capacity of an ultracapacitor by replacing the activated carbon electrode coating with an array of vertically aligned nanotubes. The nanotubes can be grown directly on the electrode using chemical vapor deposition (CVD). The nanotube array offers about 5X the surface area, a more regular structure that is more easily accessible to the electrolyte ions, and a more inert surface than activated carbon, which suggests operation up to 3.5 or 4 volts rather than the 2.7 volt limitation of activated carbon devices (energy is proportional to v^2).

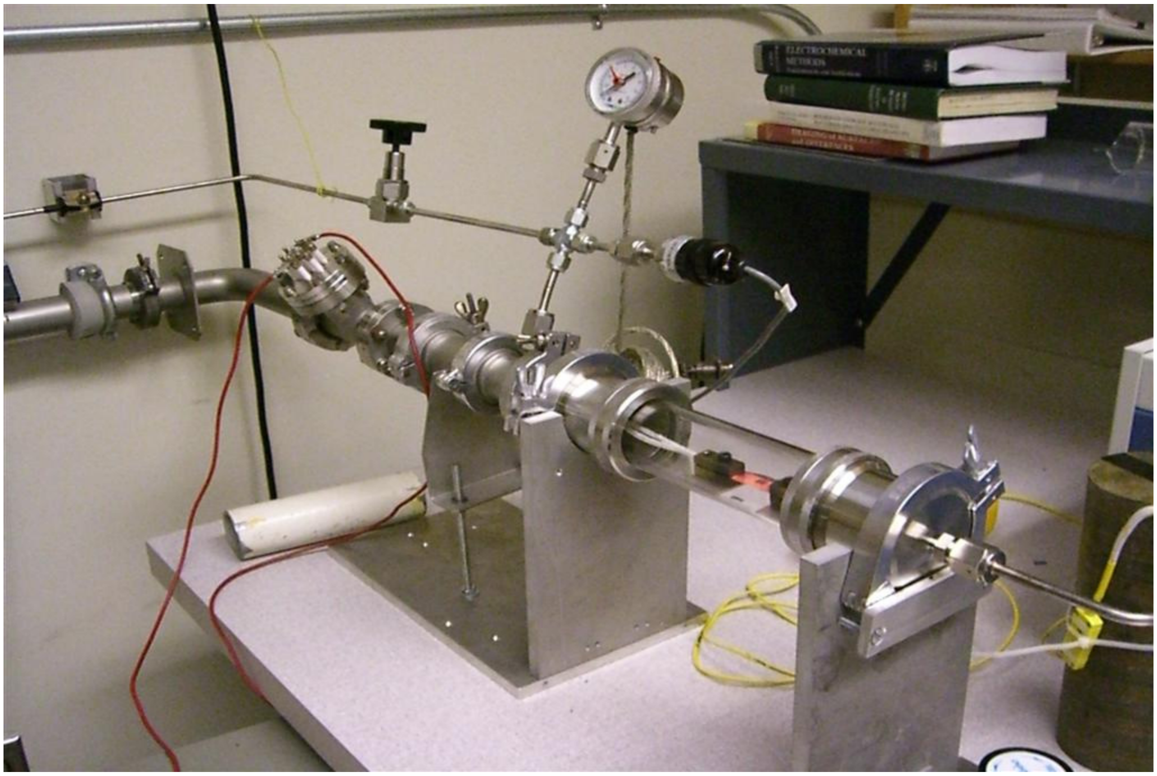
Calculations indicate that this structure could achieve an available energy storage density of 25% to 50% that of a lithium battery. In deep cycle applications, lithium ion batteries are typically operated over less than 50% of their total capacity in order to increase their lifetime, while ultracapacitors can be cycled over nearly their full range, so the nanotube-enhanced ultracapacitor could offer almost the same usable energy, while providing significantly higher power, faster recharge, easier recyclability, and almost unlimited lifetime.

Our group has successfully fabricated electrode material using a reactor designed and assembled in LEES. CVD nanotube growth is normally done on a silica substrate, and considerable effort was required to find processes to grow the nanotubes directly on a conductive aluminum substrate. We have successfully accomplished this. Initial testing of this electrode material in assembled test cells confirms ultracapacitor performance, and appears to indicate storage densities (and power densities) several times greater than today's commercial ultracapacitors.

Further work to commercialize this technology is being carried on by FastCAP Systems (using technology that is being licensed through the MIT Technology Licensing Office) under a $5M award that was granted from the first round of ARPA-E DOE stimulus funding. FastCAP Systems is a small business established by former RLE/LEES postdoctoral researcher Riccardo Signorelli.



Nanotube-Enhanced Electrode Cross Section (photo by R. Signorelli)



Reaction Chamber and Vacuum Lines (photo by J. Schindall)

2. Hybrid Ultracapacitor-Battery Power Source for Improved Battery Lifetime

Sponsors
MIT-Portugal Program
Emanuel Landsman Fund

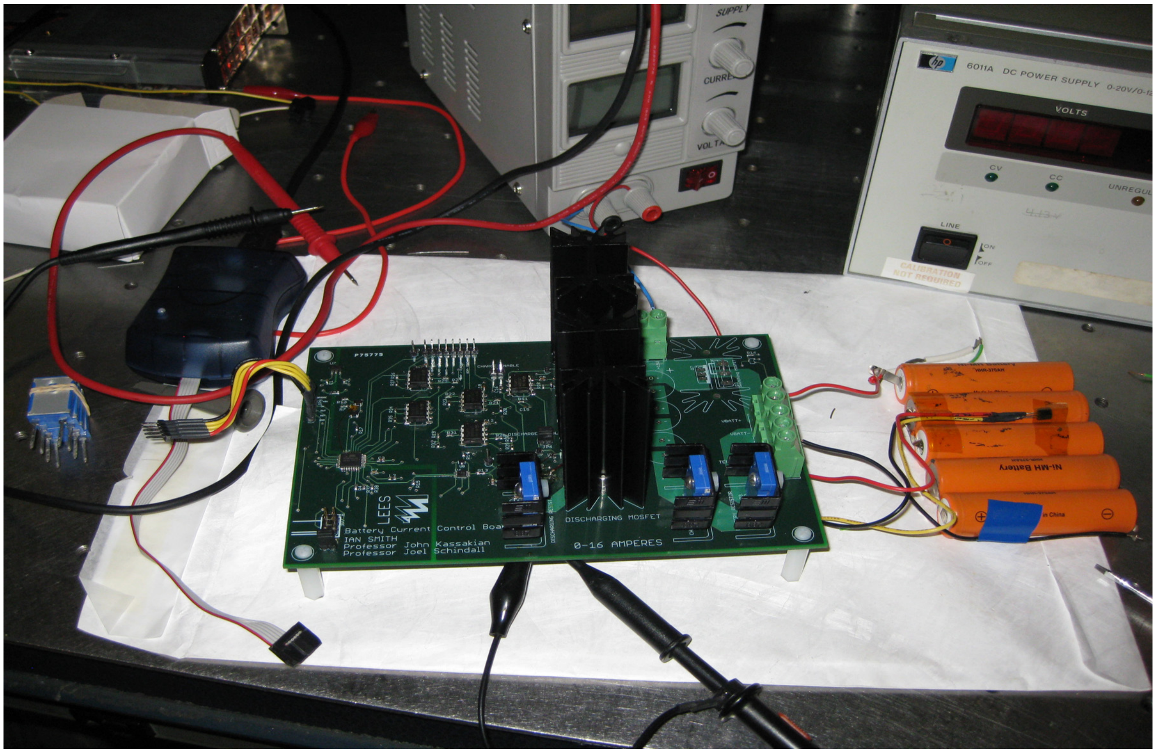
Project Staff
I. Smith, J. Kassakian, J. Schindall

Heavy duty batteries for applications ranging from power tools to electric automobiles are a design compromise between peak power (fewer, larger plates) and maximum energy storage (more, narrower plates), and their lifetime is severely compromised by periods of heavy power drain which creates heat and encourages secondary non-reversible chemical reactions. On the other hand, an ultracapacitor is well suited for high-rate charge and discharge, but it stores only about 5% as much energy as can be stored in an equivalent-sized battery.

It is commonly assumed that putting an ultracapacitor in parallel with a battery (using appropriate interface circuitry) could provide increased peak power, while at the same time allowing the battery to be optimized for maximum energy storage capacity (typically 2X the energy), and lengthening battery life due to the reduced peak currents during charge and discharge. However, very little data is available to experimentally verify this assumption.

The purpose of this project is to implement several battery-ultracapacitor architectures and subject them to repeated charge-discharge cycling with a profile similar to that of a commercial power drill. We will use the data that is collected to verify and quantify the presumption of increased battery life.

To date, we have designed representative configurations, designed and built the cycling circuitry, implemented a web-based interface to gather data over a period of days, weeks, or months, and begun the cycle testing. We expect this work to be completed in early 2011.



Ultracapacitor-Battery Combo Charge-Discharge Cycler Test Apparatus (board by Ian Smith)

Publications

Journal Articles, Published

R. Signorelli, D. Ku, J. Kassakian, J Schindall, “Electrochemical Double-Layer Capacitors Using Carbon Nanotube Electrode Structures,” *Proceedings of the IEEE, Volume 97, No. 11*, Invited Paper, November, 2009, pp. 1837-1847.

J. Schindall, “A New Model for Regenerative Electrical Energy Storage,” *IEEE Power Electronics Society Newsletter, First Quarter 2008,* January 2008, pp. 32-34.

j. Schindall, “The Charge of the Ultracapacitors, Nanotechnology Takes Energy Storage Beyond Batteries,” *IEEE Spectrum,* November 2007, pp. 42-46.

Presentations and Talks

Presentations and talks at ASME NanoEnergy Conference (keynote), Carnegie-Mellon University, University of Texas at Austin, DOE LERDWG meeting (invited twice), Florida Supercapacitor Seminar on Double Layer Capacitors and Hybrid Energy Storage Devices (invited presentation 2004, 2005, 2007 and 2008), IEEE CPMT Group presentation (invited, 2007), NASA Goddard (invited), Technology Review Emerging Technologies Conference (invited), and others.